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Selby, Katherine A. orcid.org/0000-0002-3055-2872, Roe, Helen M., Wright, Alexander J. et al. (2 more authors) (2021) Saltmarsh archives of vegetation and land use change from Big River Marsh, SW Newfoundland, Canada. Vegetation History and Archaeobotany. ISSN 0939-6314

https://doi.org/10.1007/s00334-021-00845-y

Vegetation History and Archaeobotany
https://doi.org/10.1007/s00334-021-00845-y

ORIGINAL ARTICLE

Saltmarsh archives of vegetation and land use change from Big River Marsh, SW Newfoundland, Canada

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Received: 13 December 2020 / Accepted: 27 May 2021

Abstract

Pollen and plant macrofossils are often well-preserved in coastal sediments, providing a palaeoenvironmental record of sea-level and landscape change. In this study, we examine the pollen and plant macrofossil assemblages of a well-dated saltmarsh sediment core from southwest Newfoundland, Canada, to establish recent coastal vegetation and land use change, to increase the knowledge of anthropogenic activities in the area and develop pollen chronozones for reconstructing marsh accumulation rates and to examine the representation of plant macrofossil remains in the wetland pollen profile. Grouping the pollen record into upland and wetland assemblages allows local events related to hydrological change to be separated from landscape-scale changes. The wetland pollen and plant macrofossil records indicate a general acceleration in sea-level rise ca. AD 1700. The sedge pollen and plant macrofossil records attest to multiple phases of rhizome encroachment during inferred periods of marine regression. Two chronozones are identified from the upland pollen profile; the first associated with the settlement of St. George's Bay ca. AD 1800, signalled by increases in *Plantago lanceolata* and *Ambrosia* pollen; the second with the permanent settlement of the Port au Port peninsula ca. AD 1850, indicated by increased *P. lanceolata* and *Rumex* pollen. Comparison of the plant macrofossil and wetland pollen profiles highlights the underrepresentation of grass pollen preserved in the saltmarsh sediments and a need for further analysis of the zonation, pollen dispersal and macrofossil representation of sedge species in saltmarshes.

Keywords Saltmarshes · Pollen stratigraphy · Plant macrofossils · Age-depth model · Chronozones

Introduction

Saltmarshes as archives of land-use change

Saltmarshes are highly dynamic environments that possess an intrinsic vertical and horizontal relationship with sea level, producing near-continuous records of sediment accumulation over time (Barlow et al. 2013; Brain et al. 2015; Wright et al. 2017). As such, they are commonly used for reconstructions of past sea-level change (Long et al. 2014; Kemp et al. 2015; Barnett et al. 2016). Saltmarshes accumulate sediment and plant remains to maintain their position in the tidal frame in response to relative sea-level (RSL) rise (Kemp et al. 2018). Analysis of microfossil assemblages within saltmarsh sediments, such as Foraminifera, diatoms and testate amoebae, can be used to estimate marsh surface height above mean sea level (Gehrels et al. 2001; Strachan et al. 2015; Wright et al. 2017). Radiocarbon dating of associated plant macrofossil remains provides age control for RSL reconstruction, whilst the age of horizons that are not dated directly can be inferred by interpolation (Kemp et al. 2011, 2018; Wright et al. 2017). The accuracy of the reconstructions produced is determined by the variance of the saltmarsh stratigraphy and lithology, the frequency of horizon dating and the accuracy of the age-depth model employed (Barlow et al. 2013; Wright et al. 2017). Relative sea-level reconstructions based on foraminiferal analyses from saltmarsh sediment cores undertaken by Wright et al. (2011) and Kemp et al. (2017) demonstrate the potential decimetre-scale

Communicated by K. Brown.

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Published online: 21 June 2021

precision of this method when compared with modern tide-gauge datasets.

Studies employing age-depth modelling of saltmarsh sediments in the northwest Atlantic region acknowledge the necessity of additional dating proxies (beyond radiocarbon dating) to precisely date recent (the last ~ 300 years) and historic short-lived fluctuations in saltmarsh accumulation rates due to plateaus in the calibration curve (Barnett et al. 2017; Shaw et al. 2017; Kemp et al. 2018). Tide gauge records are usually insufficient for use in age-depth modelling as the datasets are often incomplete and document a comparatively short period of time (Batterson and Liverman 2010; Barlow et al. 2013). An evaluation of age-depth model reconstructions based on a well-dated (AMS radiocarbon) saltmarsh sediment core from Pattagansett River Marsh, Connecticut demonstrated the importance of historically dated pollen markers as a complementary dating proxy (Wright et al. 2017).

Landscape change resulting from European settlement is often well-represented in pollen records from eastern North America (e.g. Ireland et al. 2014; Kujawa et al. 2016). For example, Brugam (1978) associated the first appearances of *Ambrosia* (common ragweed) and *Rumex* (dock) pollen with the arrival of European farmers in Connecticut around AD 1700. Blarquez et al. (2018) associated an abrupt decline in *Fagus* (beech) pollen and enhanced microcharcoal levels with human forest clearance in southern Québec from AD 1800. Brugam (1978) and Anderson (1974) also identified horizons where *Castanea* (chestnut) pollen declines could be associated with the chestnut blight which originated in New York from AD 1904. These studies highlight the potential of pollen markers for correlating saltmarsh palaeorecords between sites, reconstructing marsh accumulation rates, as well as providing independent cross-validation of AMS radiocarbon and ^{210}Pb derived datasets. Roe and van de Plassche (2005) demonstrated that patterns also exist in the local pollen assemblages of modern saltmarsh vegetation zones, which can be related to established tidal datums. Saltmarsh pollen assemblages were thus shown to have significant potential in studies of sea-level change. More recent studies by Kemp et al. (2009, 2011, 2014) have applied pollen chronohorizons as a complementary dating approach in saltmarsh age-depth modelling. In this paper, we examine whether pollen stratigraphic markers can be established for a well-dated saltmarsh in Newfoundland, Canada (Fig. 1). Pollen analysis of saltmarshes in the region is minimal, with the only known palynological investigation undertaken by Brookes et al. (1985) at Hynes Brook Marsh. There is therefore a need for additional chronological information to increase knowledge of the anthropogenic activities in the area and to aid the precision of RSL inferences. This research will enhance the understanding of the late Holocene vegetation history of Big River Marsh and the surrounding upland area. The three major objectives of the research were: (1) To investigate recent coastal vegetation and land use change of the study site through detailed stratigraphic pollen and plant macrofossil analyses of the saltmarsh sediments; (2) to compare the record of vegetation change to local and regional historic events to develop pollen chronozones; (3)

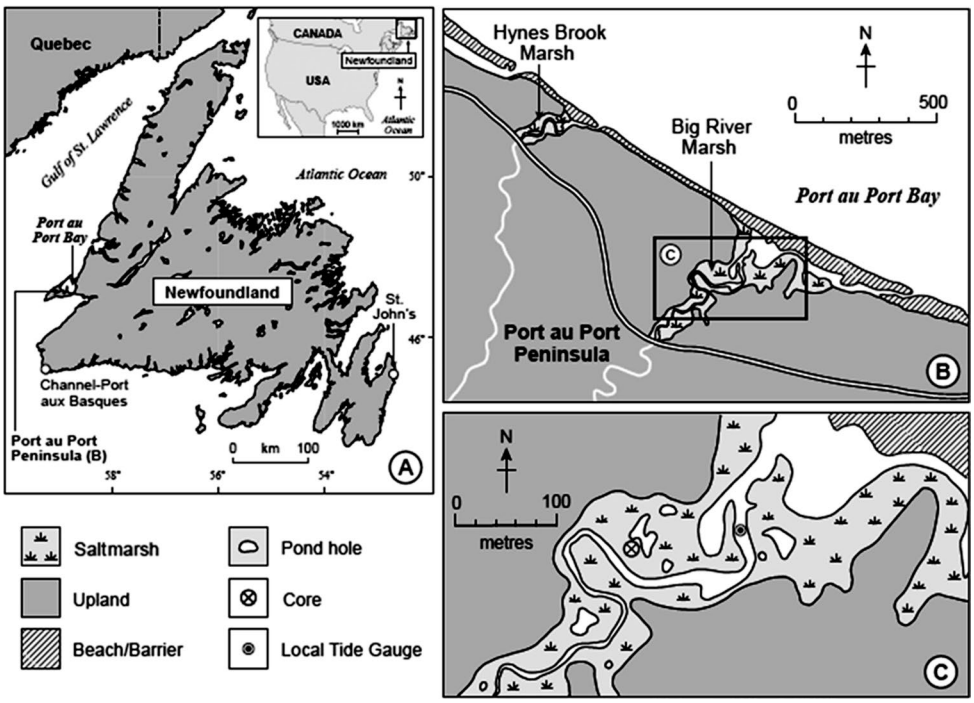

Fig. 1 Location of the study site in Newfoundland, Canada. The location of the Port au Port Peninsula (**A**), the location of the Big River Marsh study site and the nearby site of Hynes Brook Marsh on the Port au Port Peninsula (**B**) and the basic geomorphology and sample core location of Big River Marsh are shown (**C**)

to examine the representation of plant macrofossil remains in the wetland pollen profile.

Study area

Studies undertaken by Kemp et al. (2017, 2018) and Wright et al. (2011, 2017) demonstrate that saltmarsh sediments in Newfoundland have yielded well-preserved microfossils and plant remains, revealing an archive of foraminiferal assemblages extending through the mid to late Holocene which have been used to produce age-depth models for RSL reconstruction. Mid to late Holocene RSL records from the saltmarshes of Newfoundland demonstrate the variability of local RSL reconstructions within a single region, with areas in the south and southwest of the province showing a RSL rise and areas in the northwest showing static/falling sea levels (Liverman 1994; Bell et al. 2005; Daly et al. 2007; Billy et al. 2015; Kemp et al. 2018). Variable rates of RSL are mainly attributed to the proximity of Newfoundland to the margin of the former Laurentide ice sheet and the position of the hinge line between areas experiencing RSL rise and RSL fall caused by ongoing glacio-isostatic adjustment (GIA). Newfoundland is therefore an important location for investigating regional, non-linear drivers of RSL (Daly et al. 2007; Kemp et al. 2018). Crustal subsidence due to ocean loading of the Scotian shelf and 20th century eustatic sea level changes caused by global warming have also caused differential changes in RSL in the region (Gehrels et al. 2004). As global sea-levels continue to rise and storm events increase in severity, many lowland areas could be severely impacted, leading to increased coastal flooding and erosion (IPCC 2019). Although saltmarshes can maintain their position in the tidal frame in response to steady rates of RSL rise (Kemp et al. 2018), saltmarsh accumulation may not be able to keep pace with accelerated rates of RSL rise in the future. Understanding trends in late Holocene RSL in Newfoundland is therefore imperative for mitigating against the potential impacts of accelerated RSL rise.

Big River Marsh, southwest Newfoundland, was selected as the study site based on previous studies of the saltmarsh and the neighbouring site of Hynes Brook Marsh (Fig. 1) (Daly et al. 2007; Wright et al. 2011; Kemp et al. 2017, 2018), which demonstrated that the sediments yield near-continuous records of RSL extending for at least the last 3,000 years. From analysis of preserved assemblages of Foraminifera and age-depth modelling constrained by AMS radiocarbon dates and elemental abundance lead-isotope analysis, Kemp et al. (2018) concluded that RSL had risen by ~ 3 m at the site over the last 3,000 years, with 20th century RSL occurring at the fastest century-scale rate of the study period.

Big River Marsh has developed in the shelter of a barrier beach at the mouth of Big River, on the southern coast of West Bay (Fig. 1), one of two basins formed between Long Point, the Port au Port isthmus and the west coast of Newfoundland (Brookes et al. 1985). The saltmarsh is underlain by approximately 3 m of saltmarsh peat and is presently fed by small streams (Wright and van de Plassche 2001). The diurnal tidal range (mean lower low water to mean higher high water) is 1.06 m (Kemp et al. 2018). Monthly average air temperatures reach ~ 16 °C in summer and are below freezing from December to March (Canadian Climate Normals for 1971–2000, Stephenville A 48° 32′ N, 58° 33′ W).

Bertness (1991) describes the zonation of saltmarsh plants in the region as being comprised of a low marsh habitat which is covered daily by tides (low marsh), a high marsh habitat which borders the sea (high marsh), and a high marsh habitat which borders the hinterland (upper marsh). A clear vegetation zonation is evident on the saltmarsh. The low marsh zone is dominated by *Spartina alterniflora* (smooth cordgrass), which is characteristic of most Newfoundland low marsh zones (Thannheiser 1981), and *Salicornia* (glasswort) spp. The high marsh zone is characterised by *Spartina patens* (saltmeadow cordgrass), *Distichilis spicata* (seashore saltgrass), *Plantago maritima* (sea plantain) and *Triglochin maritima* (saltmarsh arrow-grass), and the upper marsh by *Iva annua* (marsh elder), Cyperaceae (sedge) and some *Juncus* (rushes) spp. At the landward limit of the marsh, vegetation is dominated by Cyperaceae and Poaceae (grasses) alongside *Abies balsamea* (balsam fir), *Pinus* (pine) spp., *Betula* (birch) spp., *Iris versicolor* (blue flag) and *Iva annua*. The regional vegetation is mainly coniferous forest, of which *A. balsamea* is the dominant tree species, alongside lesser amounts of *Picea glauca* (white spruce), *P. mariana* (black spruce) and *Pinus strobus* (white pine) (Levac 2003).

Limited Holocene pollen records from western Newfoundland (Brookes et al. 1985; Brown Macpherson 1995; Levac 2003; Levac et al. 2018) show that vegetation change correlated with fluctuations in the Atlantic Meridional Overturning Circulation, which plays a vital role in regulating climate in the North Atlantic region (Blundell et al. 2018). The Holocene vegetation record commenced with *Betula* and *Alnus* (alder) shrubland from 11 to 9.5 kyr BP, followed by an expansion in *Picea,* signalling spruce forest establishment (Levac 2003). Between 9.5 and 6.5 kyr BP, boreal forest became established in the area, with *Picea* and *Pinus* coniferous forest and *Betula* shrubland (Brown Macpherson 1995; Levac 2003). Evidence of a delay in *Pinus* forest establishment in coastal areas of southwestern Newfoundland suggests that ocean temperatures remained low in this period (Brown Macpherson 1995). From 6.5 to 4 kyr BP, tree pollen abundance increased with greater amounts of *Pinus* and deciduous species; signifying warmer summers and a longer growing season than at present (Brown Macpherson 1995; Levac 2003). Pollen records from the last 4,000 years indicate a cooler, wetter climate with a decline in *Pinus*

species and an increase in *Picea* forest with areas of shrubland (Brown Macpherson 1995; Levac 2003). European settlement of western Newfoundland is indicated in pollen records by increases in *Ambrosia* and graminoid taxa from around 400 years BP (Levac 2003; Levac et al. 2018). In the Port au Port peninsula, anthropogenically induced vegetation changes are likely evident at the end of the 1700s when Acadian settlers developed an economy in the area based on farming and fishing (Butt 2017). Mannion (1977) notes that populations increased from 20 families to 1600 people by the end of the 1800s, as the area became a productive lobster fishing site, and railway construction brought new businesses and services. A second wave of settlement is discussed by Butt (2017) in the early 1900s, as French settlers occupied the westernmost extremities of the peninsula. Earlier small-scale vegetation changes may be evident when marine-orientated ancestors of the Beothuk people (Cow Head, Beaches and Little Passage complexes) inhabited the island from ca. 2,000 to 400 years BP (Westley et al. 2011). Archaeological sites dated to the period are evident across the Port au Port Peninsula (Tourism, Culture, Arts and Recreation, ND) and a large chert outcrop identified by Simpson (1986) at West Bay may have drawn prehistoric populations to the area. There is the possibility that Norse settlers who briefly inhabited northern Newfoundland at ca. AD 1000 may have frequented other coastal areas of the island (Westley et al. 2011).

Methodology

Field methods

Stratigraphic investigations were undertaken in the field using a hand-held Dutch peat auger and the sediments logged according to the Troels-Smith (1955) classification system. A representative sample core was collected for micropalaeontological and sedimentary analyses from an undisturbed marsh location away from the Big River Marsh tidal channel (Fig. 1). The core (hereafter referred to as core BRM1) was extracted with overlapping segments using a Russian corer. The core sections were placed in plastic guttering and sealed with plastic film, before transit to the Netherlands. Here they were stored under refrigerated conditions (ca. 4 °C) prior to analysis. To establish marsh surface elevations, a temporary benchmark (wooden post) was buried in the marsh sub-surface, and core BRM1 and reconnaissance boreholes were surveyed into this point. The surface elevation of the BRM1 core was established at 0.11 m above NAD83 (North American Datum 1983).

Laboratory methods

The upper metre of the BRM1 core was used to investigate the potential for developing pollen-delimited chronostratigraphic horizons associated with human settlement and regional vegetation change, and to examine the significance of the wetland pollen and plant macrofossil remains.

Radiocarbon dating and age-depth model: The radiocarbon dates (Table 1) and age-depth model were derived from a previous study of Big River Marsh, in which core BRM1 was subsampled for Foraminifera and testate amoebae analysis (see Kemp et al. (2018) for full methodology). Fourteen AMS radiocarbon dated samples of plant macrofossil remains (palaeomarsh-surface indicators) provide a detailed chronology for the upper (104 cm) sediments of BRM1 (Table 1). To facilitate comparisons between the historical land use records and the radiocarbon dated core, all ^{14}C dates were calibrated to calendar years (2σ) using the probability method in CALIB version 6.0.2 (Stuiver and Reimer 1993; Stuiver et al. 2005) and the IntCal09 atmospheric dataset (Reimer et al. 2009). The original 'field' depth of core Sect. 2 has been subject to vertical adjustment, following cross correlation of pollen and loss-on-ignition data with core 1, by 6 cm following (bio-) stratigraphic correlation.

The age-depth model was constructed using the Clam code (Blaauw 2010) written in R (R Development Core Team 2010). One thousand iterations of LOWESS smoothing (initially spanning 0.75) were used to interpolate between dated horizons ('best' single age by weighted mean ± 95% confidence interval). A LOWESS span of 1.0 was favoured as a more rigid smoothing was considered appropriate for the short length of the series. The modern analogue technique (MAT) was applied to gauge similarity between assemblages of modern and fossil Foraminifera (e.g. Gehrels 2000; Hayward et al. 2004). Weighted averaging-based transfer function methods extracted the elevation of species optima and tolerance within the local tidal frame and these were applied to reconstruct the height at which fossil Foraminifera assemblages formed relative to palaeotide levels.

Pollen and other palynomorphs: Saltmarsh sediments were sampled at 2 cm increments throughout the sediment core. Pollen preparation followed standard procedures (Barber 1976). Samples (1–3 cm^3) were boiled with 20–25 ml 10% potassium hydroxide (KOH) and then sieved through a 200–250 micron mesh. The samples were centrifuged for 1 min at 2,000 rpm, before acetolysis and heavy liquid separation procedures were undertaken. The samples were stored in glycerol.

Pollen was counted using a light microscope under 400× magnification. To ensure that pollen derived from both the wider landscape (upland) and from the saltmarsh itself (wetland) was well represented, at least 500 pollen grains were

Table 1 Radiocarbon dates for core sections 1 and 2 (after Kemp et al. 2018)

UtC	No	Depth (cm)	Core section	Datedmat	PMS (cm)	$\delta^{13}C$ (‰)	^{14}C age ± 1σ	Median (AD)	2σ ranges (AD)
10,371	1	9–11	1	*Sp*	5 ± 4	− 13.8	− 14 ± 31	–	Modern (post 1950's)
10,372	2	17–19	1	*Sp*	13 ± 4	− 12.3	76 ± 29	1850	1691–1729 1810–1922 1952–1954
10,373	3	25–27	1	*Sp*	21 ± 4	− 12.3	143 ± 41	1807	1667–1782 1797–1893 1906–1953
10,374	4	33–35	1	*Sp*	29 ± 4	− 12.8	176 ± 31	1772	1655–1696 1725–1814 1835–1877 1917–1952
10,375	5	41–43	1	*Cr*	41 ± 1	− 26	125 ± 39	1824	1673–1778 1799–1898 1901–1942 1950–1953
10,376	6	49–51	1	*Cr*	49 ± 1	− 26.4	125 ± 35	1826	1675–1777 1799–1897 1902–1941 1950–1953
10,517	10	55–57	1	*Sp*	51 ± 4	− 13.2	233 ± 26	1667	1638–1681 1739–1744 1763–1802 1938–1951
10,516	9	61–63	1	*Cr*	61 ± 1	− 26.5	286 ± 33	1571	1491–1602 1614–1665 1786–1792
10,515	8	67–69	1	*Cr*	67 ± 1	− 26.8	332 ± 34	1560	1471–1643
10,470	7	75–77	1	*Sp*	71 ± 4	− 12.7	367 ± 33	1522	1448–1529 1543–1634
10,518	11	81–83	1	*Sp*	77 ± 4	− 12.1	415 ± 40	1474	1423–1523 1559–1563 1571–1630
10,519	12	81–83	2	*Sp*	77 ± 4	− 13.1	530 ± 34	1409	1317–1353 1389–1442
10,520	13	89–91	2	*Sr*	87.5 ± 2.5	− 13.6	546 ± 42	1392	1304–1365 1384–1440
10,521	14	102–104	2	*Tm*	102 ± 1	− 28.1	846 ± 38	1195	1048–1086 1123–1138 1150–1267

Dated plant macrofossils include: (*Sp*) *Spartina patens*; (*Cr*) *Carex rostrata*; (*Tm*) *Triglochin maritima*; (*Sr*) *Scirpus robustus*. Abbreviations: (Depth) = laboratory adjusted sample depth in core; (PMS) = estimated depth of palaeo-marsh surface; ($\delta^{13}C$) = abundance of ^{13}C relative to ^{12}C with respect to PDB reference; (^{14}C age ± 1σ) = ^{14}C age in years before present (BP) with associated 1σ error and normalised to $\delta^{13}C = -25$ ‰; (Median) = median calibrated age in calendar years (AD), 2σ ranges; calibrated 2σ age ranges in calendar years (AD)

counted per level. Pollen and spore taxa were identified with reference to the keys of McAndrews et al. (1973), Faegri and Iversen (1989) and Moore et al. (1991). Pollen percentage profiles were constructed using C2 software (Juggins 2007) (Figs. 3, 4). To avoid any potential errors in distinguishing the dispersal of pollen grains from transitional vegetation communities, the pollen was sub-divided into three main source groupings: upland, wetland and indeterminate source (Table 2), following the approach used by Roe and van de Plassche (2005). The upland group includes pollen from taxa which grow in the marginal upland and hinterland of the study area, while the wetland taxa comprise those which are commonly found in intertidal marshes, including Poaceae. The indeterminate group comprises pollen which cannot be defined as being derived from either upland or wetland sources. Grouping the taxa in this way allows both regional (upland) land use change events and fluctuations in local (wetland) saltmarsh conditions to be examined.

The pollen diagrams were zoned using Constrained Incremental Sums of Squares (CONISS) cluster analysis, undertaken in R version 3.6.1 (R Core Team 2019) using the rioja package (Juggins 2017). Foraminiferal test linings and

Table 2 Pollen taxa source area groups (following Roe and van de Plassche 2005)

Upland	Indeterminate Source	Wetland
Pinus	*Artemisia*	Poaceae
Betula	Caryophyllaceae	Cyperaceae
Picea	Asteraceae	*Potamogeton*
Abies	Brassicaceae	*Armeria maritima*
Carya	*Equisetum*	Chenopodiaceae
Quercus	Ericales	Caryophyllaceae
Acer	*Filipendula*	*Elodea*
Alnus	*Menyanthes trifoliata*	*Lycopodium lucidulum*
Ulmus	Lamiaceae	*Lycopodium*
Castanea	Cichorieae	*Typha latifolia*
Fraxinus	*Lilium martagon*	*Typha angustifolia*
Ostrya	*Polygonum*	*Polypodium*
Carpinus	Ranunculaceae	*Selaginella selaginoides*
Corylus	Rosaceae	
Ilex	*Sanguisorba*	
Salix	Apiaceae	
Ambrosia	*Filicales*	
Plantago lanceolata	*Sphagnum*	
Plantago		
Rumex		

other non-pollen palynomorphs (e.g. fungal spores) were also enumerated, when present, and are included in the wetland pollen diagram (Fig. 4). Microscopic charcoal identified on the pollen slides was counted following the method outlined by Clark (1982) and included in the upland pollen diagram (Fig. 3).

Plant macrofossils: These were analysed at 1 cm intervals contiguously throughout the BRM1 core following the methods outlined by Mauquoy et al. (2010), whereby subsamples (5 cm^3) were treated with 5% KOH and heated for 45 min, then disaggregated in cold water and washed through a 100 µm sieve. The macroscopic plant remains, typically comprising rootlets, rhizomes and sub-surface stems of intertidal grass and sedge species, were picked from the residues using a low power microscope and identified through comparison with modern reference data. The vascular plant remains identified are expressed in percentage values of the total volume of sieved sediment. Plant macrofossil percentage profiles were plotted using C2 software (Juggins 2007) (Fig. 5) and the plant macrofossil diagram was zoned using CONISS cluster analysis, undertaken in R version 3.6.1 (R Core Team 2019) using the rioja package (Juggins 2017).

Loss-on-ignition: The non-volatile organic matter content of the sample core was determined using the loss-on-ignition method outlined by Heiri et al. (2001). Sampling was carried out at 2 cm increments throughout the core. The samples were weighed in crucibles before being dried in an oven at 105 °C for 12 h and the dry weight recorded. The samples were then placed in a muffle furnace at 550 °C for 3 h before recording the final post-ignition weight (samples were left to cool in a desiccator between each stage). Organic matter content was calculated using the formula:

$$\mathrm{LOI550} = ((\mathrm{DW105} - \mathrm{DW550})/\mathrm{DW105})) * 100 \quad (1)$$

where LOI550 represents the post combustion weight of the sample as a percentage, DW105 represents the dry pre-combustion weight of the sample and DW550 represents the post combustion weight.

Results

Stratigraphy, radiocarbon dating and age-depth model

The stratigraphy at Big River Marsh consists of a substrate of glacially derived consolidated, grey-blue silt and clay, overlain by saltmarsh peat with abundant plant remains (Kemp et al. 2018). The BRM1 core was composed entirely of high and upper marsh peat (Fig. 2). A total of 14 radiocarbon dates obtained on plant macrofossils in the sample core (Kemp et al. 2018; Table 1) reveal that the upper metre of sediment accumulated during the past ~951 years. The 2σ ranges are wide, particularly in the upper 63 cm, and there is an overlap in the median calibrated age of samples taken between 57 and 25 cm, which could be a consequence of pre-treatment sample contamination (Wohlfarth et al. 1998).

The average organic content of the saltmarsh sediments (LOI; 37.6% ± 9.3; Fig. 2) generally increases through the BRM1 core (from base to top). The organic content is significantly below the mean at 63 cm (6.3%) and significantly above the mean at 47 cm (64.9%). The age-depth model indicates an accumulation rate of 1.35 mm a^{-1} in the upper metre of the core, with an apparent acceleration in palaeomarsh surface accumulation at ca. AD 1700, coincident with an increase in organic carbon (Fig. 2).

Pollen and plant macrofossils

The pollen and plant macrofossil diagrams have been divided into zones which represent the major changes of vegetation at the site. The pollen zone descriptions for upland pollen (Fig. 3), wetland pollen (Fig. 4) and plant macrofossils (Fig. 5) are shown in Table 3.

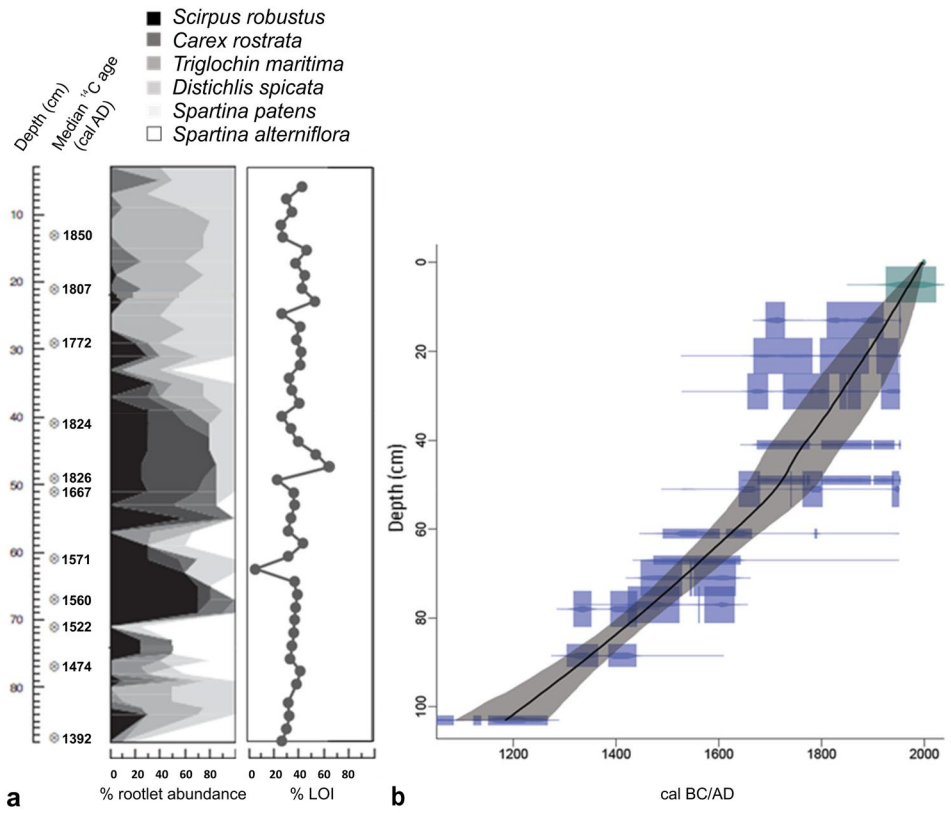

Fig. 2 **a** Graph to show the stratigraphy and Loss-on-Ignition (LOI) (%) data with increasing core depth (cm) and median ^{14}C ages from Kemp et al. (2018). **b** The age-depth model for Big River Marsh core BRM1 (after Kemp et al. 2018)

Pollen and plant macrofossil representation

The wetland pollen assemblage of the BRM1 core is dominated by Cyperaceae (up to 45%), *Potamogeton* (up to 45%) and Poaceae pollen (up to 18%), whilst the plant macrofossil assemblage includes the remains of three common saltmarsh grass species of the Poaceae family (*Distichlis spicata*, *Spartina patens* and *S. alterniflora*), two sedge species of the Cyperaceae family (*Scirpus robustus* and *Carex rostrata*) and *Triglochin martima*. A combined plot which shows the Cyperaceae and Poaceae pollen, the plant macrofossil assemblage and the Foraminifera-derived reconstruction of palaeo-marsh elevation (from Kemp et al. 2018) for BRM1 is given in Fig. 6. The plot highlights the broad correspondence in the relative abundance of the pollen and plant macrofossils for taxa in the same family. For example, in pollen zone BRW-2, where Cyperaceae levels peak, *Carex rostrata* macrofossils also reach peak abundance (up to 60%). Elsewhere in the core the *Scirpus robustus* and *C. rostrata* macrofossil remains and Cyperaceae pollen abundance show a vertical offset, e.g. *S. robustus* rootlet percentages peak between 67 and 69 cm (up to 70%) and *C. rostrata* at 47 cm, whilst Cyperaceae pollen percentages peak at 31 cm. Similarly, between 3 and 17 cm, where the remains of the two species are absent in the macrofossil record, Cyperceae pollen levels persist at 10–19%. Although the correspondence between the Poaceae pollen assemblages and the Poaceae plant macrofossil record is less well pronounced, peak levels of Poaceae pollen occur just after peak abundances of *S. alterniflora* macrofossils (70%). The Foraminifera-derived reconstruction of palaeo-marsh elevation (PME) shows little change throughout the period of deposition (Fig. 6). There nevertheless appears to be a subtle inverse relationship between the relative abundance of Cyperaceae pollen and the inferred PME in parts of the core. For example, where the lowest sedge pollen value of BRM1 (7%) occurs at 73 cm, the palaeo-marsh elevation is highest at 167 F-SWLI (standardised water level index units, where a value of 100 corresponds to mean tide level and 200 is the highest occurrence of Foraminifera), and where the highest Cyperaceae value (45%) occurs at 31 cm, the palaeo-marsh elevation is lowest at 148 F-SWLI.

Interpretations and discussion

Upland environmental changes

The upland pollen assemblage from Big River Marsh indicates a continuous presence of *Picea* and *Betula* woodland from at least ca. AD 1392 to the present day, comparing well with other studies in the region (Brookes et al. 1985; Brown Macpherson 1995; Levac 2003). Fluctuations in *Corylus*, *Alnus* and herb pollen indicate phases of hydrological

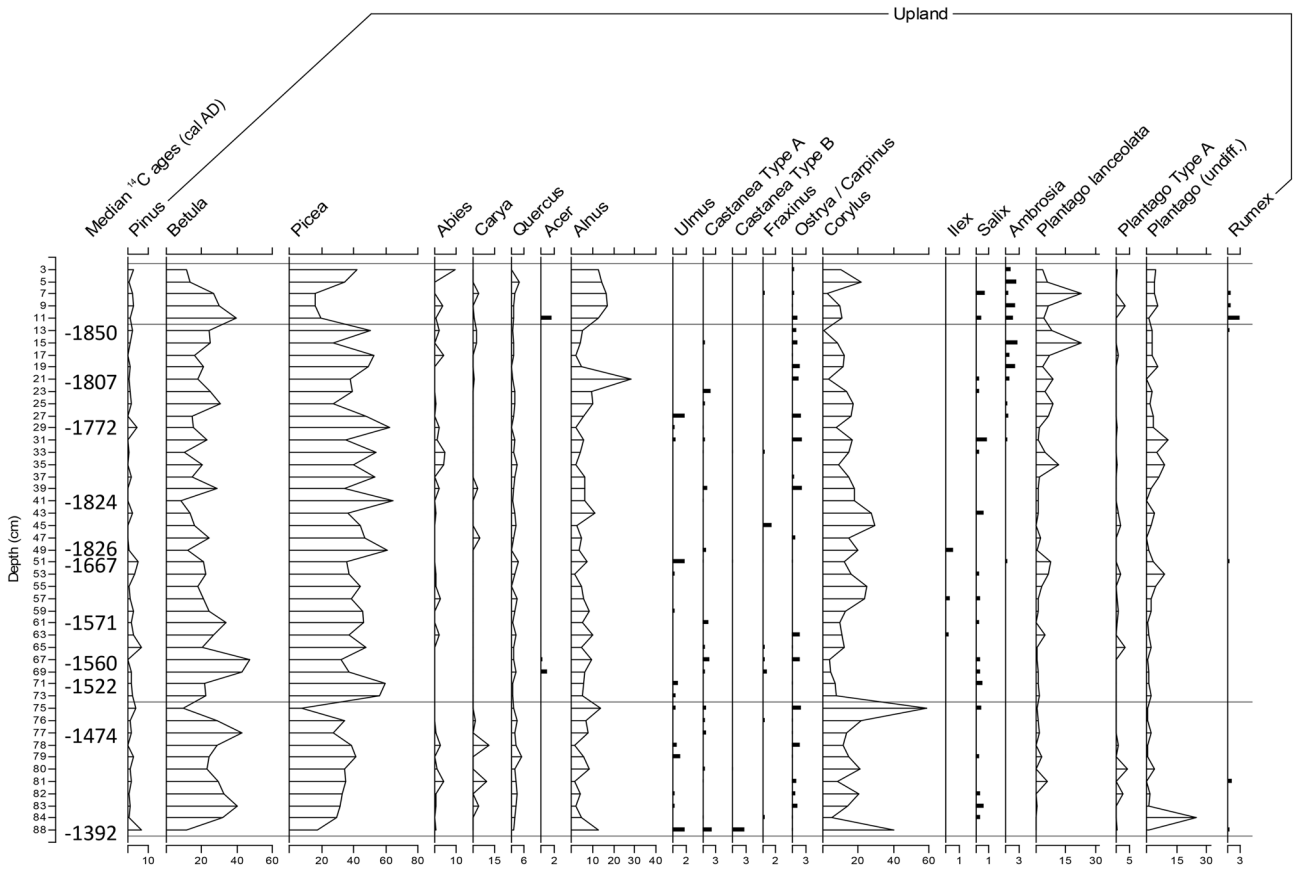

Fig. 3 Percentage upland and indeterminate source pollen and spore frequency diagram from Big River Marsh core BRM1

change and subtle human-induced vegetation changes in the area surrounding the saltmarsh.

Ca. AD *1392–1522*: From ca. AD 1392, consistently high pollen concentrations indicate a relatively dense coverage of *Betula* and *Picea* forest, with a *Corylus* and *Alnus* shrub understorey. High levels of undifferentiated *Plantago* (plantain) pollen in the lower assemblage may indicate *P. maritima* expansion in the high marsh. The increase in microcharcoal levels at 80 cm accompanies a slight reduction in *Betula* pollen and increased *Plantago* pollen levels. Disturbance could be attributed to ancestors of the Beothuk, whose presence in the area is indicated by the local assemblage of artefacts of the Little Passage complex (Simpson 1986). The ancestral Beothuk appeared to favour sheltered coastal sites such as Big River Marsh, allowing them to exploit the resources of both the coastline and the surrounding uplands (Pastore 1989; Holly et al. 2015). Similarly, at ca. AD 1500, there are significant decreases in *Betula* and *Picea*, corresponding with notable peaks in *Corylus* and Asteraceae (aster) pollen, and an increase in *Alnus*, indicating a further disturbance event. *Corylus* pollen production is often enhanced in disturbed environments (Bégeot 1998) and has been correlated with increased forest fire events in some studies (Finsinger et al. 2006). The ca. AD 1500 disturbance event could be attributed to a local natural or human-induced forest fire, although there is no corresponding peak in microcharcoal levels.

Ca. AD *1522–1850*: From ca. AD 1522, an increase in *Picea* pollen frequencies signifies increased *Picea* forest coverage with fluctuating levels of *Betula, Corylus* and *Alnus* shrubs. At ca. AD 1600 there is also a prolonged period of low microcharcoal levels, indicating reduced forest fire frequency. Reforestation may signal a withdrawal of ancestral Beothuk populations from the area. The event coincides with an overall decline in native populations across the region, instigated by European colonisation (Pastore 1989; Liebmann et al. 2016). From ca. AD 1650 there is a steady increase in *P. lanceolata*, indicating an increase in disturbed, open and grassy areas (Clapham et al. 1987). The increased disturbance could be attributed to the presence of nomadic human populations in the area. The presence of the Mi'kmaq people is documented in southern Newfoundland from at least the early 1500s (Martijn 2003). Historic accounts suggest that the Mi'kmaq frequented coastal areas at the mouth of big rivers (such as Big River Marsh) in the summer months, allowing access to fishing areas as well as providing

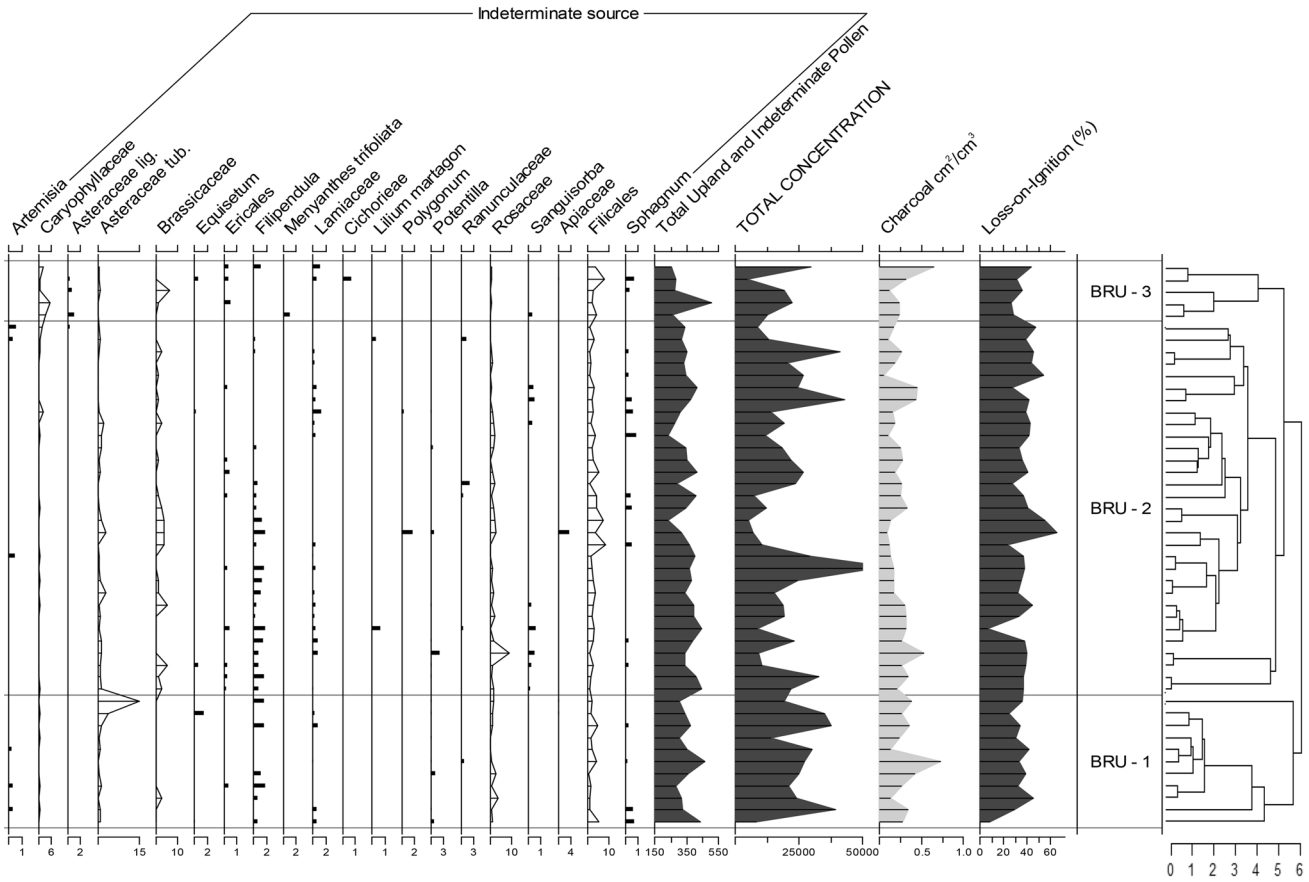

Fig. 3 (continued)

an inland transportation route for goods such as furs and hides for trade with Europeans (Martijn 2003). There is a notable peak in *P. maritima* at ca. AD 1800, alongside a small increase in *Ambrosia* pollen. Brookes et al. (1985) record a concurrent rise in *Plantago* pollen levels at Hynes Brook Marsh. The rise may coincide with a historic account from AD 1794, detailing the presence of a permanent Mi'kmaq community at St. George's Bay (approximately 10 km southwest of Big River Marsh) consisting of at least 19 families (Martijn 2003). Mannion (1977) also details the presence of European settlers in the area from the late 1700s, with 13 families of European origin documented in the St George's Bay area in AD 1818.

Post AD 1850: From ca. AD 1850 there is a notable decrease in *Picea* pollen, alongside a second peak in *Plantago lanceolata*, an increase in *Alnus, Corylus* and *Rumex* pollen and the continued presence of *Ambrosia* pollen. *Ambrosia* is frequently associated with European settlement in North American pollen records (Brugam 1978; Tolonen 1983; Fuller et al. 1998). A similar expansion of *Ambrosia* pollen is also noted in the period at the Bay of Islands (western Newfoundland) (Levac 2003). The increase in ruderal species and shrubs may be associated with land clearance and domestic grazing of the saltmarsh following increased settlement of the Port au Port Peninsula in the later 1800s (Roberts and Robertson 1986; Butt 2017; Levac et al. 2018). Barter (1986) outlines a witness account of the presence of approximately five to six hundred individuals in the St George's area in 1842, who were thought to occupy the area seasonally for fishing. The decrease in *Picea* pollen in this period could also be associated with deliberate timber felling in the region as fishermen were able to supplement their income by cutting wood for the sawmill established at Corner Brook in 1865 (Mannion 1977). Fishermen may have become more reliant on the timber industry towards the end of the century, as cod fishing stocks are thought to have become severely depleted on the west coast by 1875 (Barter 1986).

The increase in charcoal concentrations observed at the top of the pollen profile is potentially associated with increased human activity. Documentary evidence of anthropogenically derived forest fires is common around inhabited areas in the period of European settlement in Newfoundland (Jessen et al. 2011). However, microcharcoal fragments observed on pollen slides usually derive from a wide catchment and can be subject to increased breakage when

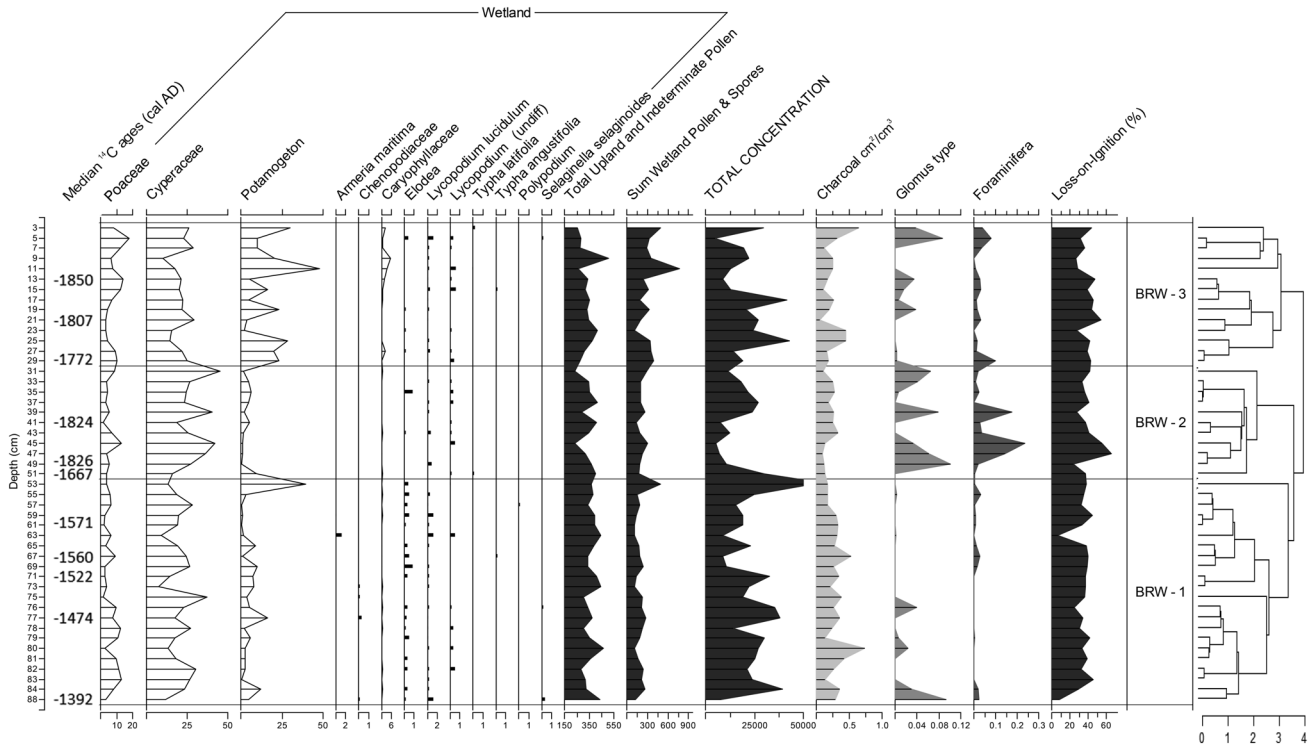

Fig. 4 Percentage wetland pollen and spore frequency diagram for Big River Marsh core BRM1

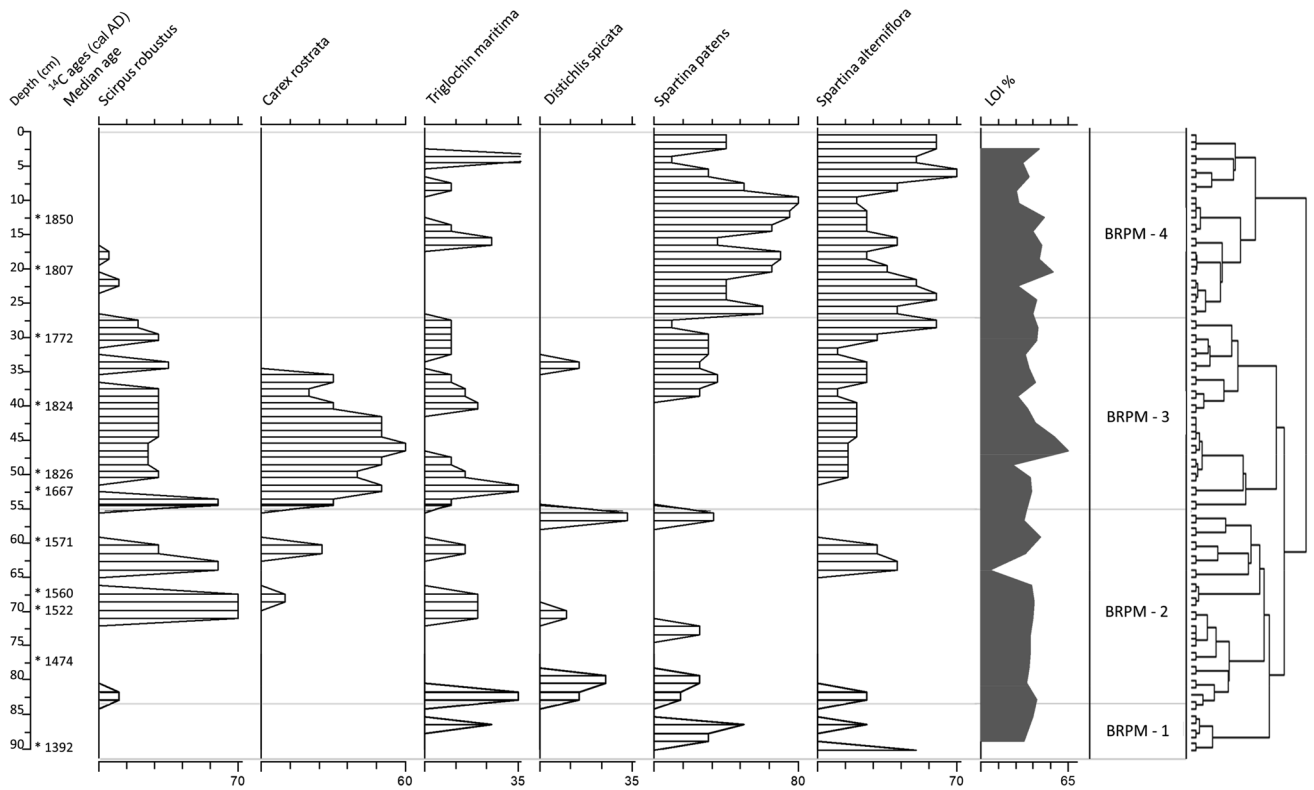

Fig. 5 Plant macrofossil diagram from Big River Marsh core BRM1

Table 3 Pollen zone descriptions for upland pollen, wetland pollen and plant macrofossils

Zone	Depth (cm)	Median ^{14}C age range (cal AD)	Zone description
Upland pollen zones			
BRU-3	0–12	Post 1850	High levels of *Picea* (up to 42%) and *Corylus* (hazel) (up to 21%) and moderate levels of *Alnus* pollen (up to 17%). *Betula* pollen decreases throughout the zone, making up 40% of upland pollen at 11 cm. *Plantago lanceolata* (ribwort plantain) peaks at 7 cm (23%). Charcoal fragments achieve 0.65 cm^{-3} at the top of the profile
BRU-2	12–74	1500–1850	High levels of *Picea* (up to 62%), *Betula* (up to 47%) and *Corylus* pollen (up to 29%). *Alnus* peaks at 21 cm (29%) and a second peak in *P. lanceolata* occurs at 15 cm (23%)
BRU-1	74–88	1375–1500	High levels of *Betula* (up to 43%) and *Picea* pollen (up to 41%) with subsidiary *Alnus* (up to 14%) and *Carya* (hickory) (up to 11%). There are peaks in *Plantago* pollen (25% at 84 cm), Asteraceae tubuliflorae (15% at 75 cm) and charcoal fragments at 80 cm. Maximum *Corylus* percentages occur in the upper part of the zone (59%)
Wetland pollen zones			
BRW-3	0–30	1750-post 1850	High levels of *Potamogeton* pollen (up to 47%), although values decline to 2% at 23 cm. Moderate levels of Poaceae pollen (up to 18%). *Filicales* spores reach 8% at 5 cm. Caryophyllaceae pollen levels reach 6% at 9 cm
BRW-2	30–52	1500–1850	High levels of Cyperaceae (up to 45%). Low percentages of *Potamogeton* (pondweed) ($\leq$6%). Lowest pollen concentrations of the profile at 45 cm. Highest concentrations of Foraminifera (up to 0.24 cm^{-3}) and *Glomus* spores (up to 0.1 cm^{-3})
BRW-1	52–88	1375–1500	High pollen concentrations (up to 59,155 cm^{-3}). Poaceae levels decrease throughout the zone. Fluctuating levels of *Potamogeton* reach a high of 40% at the top of the zone
Plant macrofossil zones			
BRPM-4	0–26	1800-post 1850	*Spartina patens* (up to 80%) and *Spartina alterniflora* (up to 70%) reach peak abundance. There are fluctuating levels of *Triglochin maritima* throughout the upper zone
BRPM-3	26–54	1600–1850	High levels of *Carex rostrata* (bottle sedge) in the lower to mid zone, reaching peak profile abundance (up to 60%), but disappearing from the profile above 35 cm. High levels of *Scirpus robustus* (seacoast bulrush) in the lower zone (reaching 60% at 54 cm), with fluctuating levels throughout the mid to upper zone. *Spartina patens* and *S. alterniflora* increase in the upper zone. Fluctuating levels of *Triglochin maritima* throughout
BRPM-2	54–83	1450–1600	*S. robustus* reaches peak abundance (up to 70%) where *S. alterniflora* rootlets are absent between 59 and 52 cm. *Distichlis spicata* peaks (33%) at 56 cm to 57 cm. Plant macrofossils are absent from some horizons (58 cm, 59 cm, 64 cm, 65 cm, 72–75 cm, 80 cm and 81 cm)
BRPM-1	83–90	1375–1450	High levels of *S. alterniflora* (50%) and *S. patens* (20%)

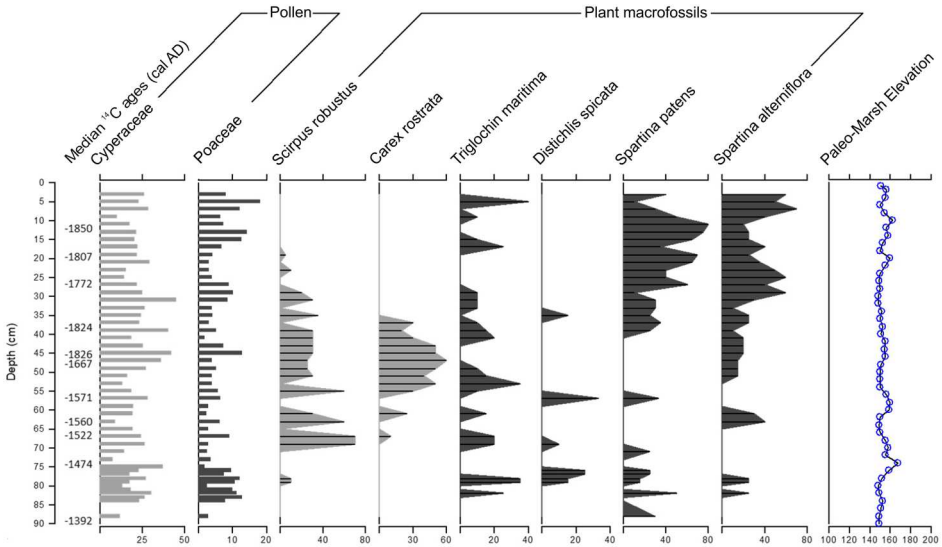

Fig. 6 Cyperaceae and Poaceae pollen and plant macrofossil diagram for Big River Marsh core BRM1, shown alongside the Foraminifera-derived reconstruction of palaeo-marsh elevation in standardised water level index (F-SWLI) units, where a value of 100 corresponds to mean tide level and 200 is the highest occurrence of Foraminifera (from Kemp et al. 2018)

transported via water (Patterson III et al. 1987; Schmidt and Noack 2000; Lindskoug and Marconetto 2019). The increase in fragment concentration in BRM1 may therefore not necessarily represent anthropogenic presence in the Port au Port region, but instances of increased wildfire, site exposure and hydrological change, particularly as peaks in microcharcoal fragments are evident from at least ca. AD 1500 at Big River Marsh.

Fluctuations in tree pollen values could also be associated with phases of hemlock looper outbreak. Arsenault et al. (2016) cite defoliating insects as the cause of the largest disturbance footprints in Newfoundland. Outbreaks are thought to occur approximately every 10–12 years in Newfoundland (Iqbal et al. 2011). Mortality levels of *A. balsamea* are found to be particularly affected by the defoliator, although a variety of other coniferous and deciduous trees are susceptible (Iqbal et al. 2011).

Upland pollen representation

Upland pollen is typically deposited on saltmarshes from a wide catchment area via a range of dispersal mechanisms, including from the hinterland of the saltmarsh (wind-dispersed), the river catchment (fluvial) and via marine tidal processes (Chmura and Eisma 1995; Roe and van de Plassche 2005; Dai et al. 2014). The upland pollen assemblage of the saltmarsh sediments at Big River Marsh are dominated by high levels of tree and shrub pollen, including *Picea* (up to 45%), *Betula* (up to 26%) and *Corylus* (up to 28%) pollen, with lesser amounts of *Alnus* (up to 18%), and fluctuating levels of herbaceous pollen. *Abies* pollen values are relatively low throughout the assemblage (< 3%). *Pinus* levels are also low (< 5%), despite the presence of the taxon in the hinterland of the modern marshland.

The high *Betula* pollen values and low *Abies* pollen levels at Big River Marsh are unlikely to represent the proportion of the taxa present in the landscape. *A. balsamea* is a dominant species in Western Newfoundland and is thought to be greatly under-represented in regional pollen records, while *Betula*, which is also a dominant regional species, is often over-represented (Brown Macpherson 1995; Jessen et al. 2011). *Pinus* is also often over-represented in pollen records, particularly in exposed coastal areas where pollen can travel from long distances via wind and marine water dispersal with minimal interception (Heusser 1983; Brown Macpherson 1995; Williams 2010). However, the low *Pinus* pollen values at Big River Marsh may indicate under-representation of the taxon, as pollen from the hinterland is able to spread over a wider distance via the southwest prevailing wind direction (Mudie and McCarthy 1994). *Picea* species are thought to be well-represented in modern regional pollen records and make up approximately 46% of the forest composition in southwest Newfoundland, indicating that the high values recorded at Big River Marsh may be representative of *Picea* presence in the surrounding landscape (Brown Macpherson 1995).

Saltmarsh vegetation changes

The wetland pollen and spore record indicates the continuous presence of saltmarsh vegetation, with a dominance of Cyperaceae and fluctuating levels of Poaceae pollen throughout, consistent with the pollen record from Hynes Brook Marsh (Brookes et al. 1985). Variable levels of *Potamogeton* pollen indicate the presence of standing or very slow moving water near to the core site (Clapham et al. 1987). The plant macrofossil assemblage provides a high resolution record of saltmarsh vegetation changes, with evidence for a significant phase of Cyperaceae expansion and subsequent retreat, possibly driven by local hydrological changes and a general shift towards an intermediate marsh vegetation composition as sea-level rise began to accelerate from ca. AD 1700 (Kemp et al. 2018).

Ca. AD 1392–1667: From ca. AD 1392, the plant macrofossil assemblage indicates that the marsh surface was populated by low and high marsh vegetation, signified by the presence of *Triglochin maritima* and common saltmarsh grass species including *Spartina patens, S. alterniflora* and *Distichlis spicata* (Clapham et al. 1987; Bertness 1991). At ca. AD 1474 (75–71 cm), there is a break in the plant macrofossil record, which coincides with a peak in the Foraminifera-derived reconstruction of palaeo-marsh elevation at 74 cm. The associated sediment-dominated layer is characterised by an increase in shrub pollen and coincides with a significant reduction in Poaceae and Cyperaceae pollen and a subsequent increase in *Potamogeton* pollen. These changes could have resulted from a short-lived increase in local sea level. This may have been associated with marsh erosion and sediment deposition, possibly driven by catchment flooding, tectonic subsidence, a storm or a tsunami which carried arboreal (shrub) pollen into the site, or a localised phase of ponding. There are also two thinner horizons (65–63 cm and 59–57 cm) at ca. AD 1550 and 1571 where there is a break in the plant macrofossil record. LOI levels fall significantly at 63 cm (6.3%), although a corresponding environmental response in the pollen record is less evident. The horizons may correspond with observations made by Kemp et al. (2018), where the presence of bands of fine-grained clastic sediments are noted in the stratigraphy at Big River Marsh, and are assigned to either the development of pools of water on the marsh or the delivery of ice-rafted sediments. The close proximity of the coring site to the main Big River channel (approximately 20 m) (Fig. 1) and to salt pannes on the contemporary marsh surface, indicate the possibility of flooding and/or salt panne development of the coring site.

From ca. AD 1500 a period of marine regression is indicated by an increase in the upper marsh species *Scirpus robustus* and *Carex rostrata* (Clapham et al. 1987; Wang et al. 2004). A brief phase of marine transgression is apparent as *D. spicata* and *S. alterniflora* increase in abundance at ca. AD 1600, before a sharp increase in *S. robustus* rootlets, *Potamogeton* pollen and overall pollen concentrations indicates a return to upper marsh conditions and increased areas of freshwater seepage in the upper marsh. The brief phases of fluctuating RSL in this period are not reflected in the reconstruction of RSL at Big River Marsh by Kemp et al. (2018), although the reconstruction of global mean sea level does show fluctuation in this period, potentially indicating eustatic changes.

Ca. AD 1667–1772: From ca. AD 1667, the prevalence of *C. rostrata* remains, a fresh-water sedge which inhabits inundated areas, alongside *S. robustus* and high Cyperaceae pollen levels, indicate that an upper marsh habitat prevailed (Barnett et al. 2017). The presence of *T. maritima* remains and Foraminifera in some horizons at this time indicate that the site continued to be impacted by tidal inundation. *Glomus* spore abundance is also high in this period and has some correlation with the rootlet percentages of *T. maritima*. Increased *Glomus* spore abundance may reflect periods of increased germination in response to increased marsh salinity (Carvalho et al. 2004). Prior to ca. AD 1772, the decline in *C. rostrata* rootlet abundance, alongside an increase in *S. alterniflora* and *S. patens* remains, suggests a transition phase on the marsh, with the presence of upper, high and low marsh species.

Post ca. AD 1772: From ca. AD 1772, the wetland pollen assemblage indicates a reduction in Cyperaceae abundance and an increase in areas of standing water on the marsh surface as *Potamogeton* pollen levels increase. Increased ponding could be attributed to the effects of local rising sea-levels, which can affect the mortality of both salt-water and waterlogging intolerant vegetation and lead to the development of depressions in the marsh in places of vegetation die-back (DeLaune et al. 1994; Brownstein et al. 2013; Raposa et al. 2017). *S. patens* and *S. alterniflora* dominate the plant macrofossil assemblage in this period, alongside fluctuating levels of *T. maritima*, indicating high and low marsh zonation and a similar vegetation composition to present day. *S. alterniflora* and *T. maritima* become more dominant from 7 cm, indicating a continuous rise in sea-level. Collectively, increased marsh surface ponding and the apparent transition to a high/low marsh vegetation composition indicates accelerated RSL in this period. The age-depth model and relative sea-level curve for Big River Marsh (Kemp et al. 2018) also indicate an apparent AD ~ 1700 acceleration in the rate of marsh-surface accumulation, concurrent with late Holocene sea level studies of Atlantic Canada (Gehrels et al. 2005; Barnett et al. 2017) and the wider NW Atlantic region (Billy et al. 2015; Kemp et al. 2015, 2018). The palaeo-marsh elevation curve shows that marsh surface elevation was largely able to keep pace with the inferred RSL rise in the period since AD ~ 1700 (Kemp et al. 2018).

Wetland pollen representation

Studies of wetland pollen representation often assume that the pollen derives from vegetation located within approximately two metres of the sampling site (Bunting 2003; Pendea and Chmura 2012; García-Moreiras et al. 2015). Roe and van de Plassche (2005) found that the primary control on wetland pollen representation of the saltmarsh surface is the proximity of the sediments to the source vegetation. The modern vegetation composition of Big River Marsh is typical of many saltmarshes in the region (e.g. Edwards et al. 2004; Byers and Chmura 2007; Coulombier et al. 2012), with Cyperaceae species in the upper marsh and the transition to high and low marsh areas marked by a dominance of saltmarsh Poaceae species. However, an apparent bias towards pollen derived from the upper marsh areas is evident throughout the wetland pollen assemblage at Big River Marsh, showing a dominance of Cyperaceae (up to 45%) and fluctuating levels of *Potamogeton* (up to 48%) throughout, while Poaceae pollen accounts for only 2 to 18% of the pollen counted. Roe and van de Plassche (2005) and Pendea and Chmura (2012) found similar results when analysing surface saltmarsh sediments, with proximate Cyperaceae vegetation well-represented in the pollen record, whilst Poaceae dominated areas of the saltmarsh were less well-represented. This may be a consequence of differences in pollen dispersal, morphological characteristics of the source vegetation or geomorphological characteristics of the marsh area from which the pollen was derived. Frequently flooded marsh areas can also be susceptible to tidal influxes or transfers of pollen away from the marsh, which may have a differential effect on high and low marsh areas dominated by Poaceae species compared to the Cyperaceae dominated upper marsh (Medeanic et al. 2016). Influxes of wetland pollen from other coastal areas could lead to relative under-representation of Poaceae pollen, whilst the transfer of pollen away from the marsh will reduce the concentration of pollen from high and low marsh areas. Cyperaceae pollen, which has high dispersibility (Fontana 2005) may also be transferred from the upper marsh to high and low marsh areas via southwest prevailing winds, leading to the potential over-representation of the vegetation in the pollen record at Big River Marsh.

Plant macrofossil representation

Comparison of the wetland pollen and plant macrofossil assemblages illustrates differential representation of the abundance and spatial distribution of saltmarsh vegetation on the marsh surface, highlighting the benefit of utilising both analysis methods. The plant macrofossil assemblage for BRM1 generally shows fluctuations between sediments dominated by the remains of Cyperaceae species and Poaceae dominated peats. However, understanding the relationship between Cyperaceae vegetation abundance and pollen abundance is more complex, with Cyperaceae pollen levels remaining high where no macrofossil remains are present, and remaining low at times where the macrofossil remains of Cyperaceae species peak. The absence of Cyperaceae plant macrofossil remains where the pollen levels are relatively high (e.g. below 80 cm) could reflect an initial expansion of Cyperaceae communities on the fringes of the marsh during a period of relative sea-level fall or stable sea levels. Cyperaceae pollen could also have been derived from adjacent areas of standing water.

The apparent delay in Cyperaceae pollen production relative to macrofossil abundance in the lower ca. 30 cm of the core may reflect Cyperaceae rhizome encroachment across the marsh during a period of stable sea levels, marine regression or a phase of enhanced freshwater seepage, possibly driven by climate change or other local hydrological changes. Cyperaceae rhizomes can extend away from swards on the fringes of marshes, resulting in the presence of below-ground biomass before pollen-producing above-ground biomass develops. This would generate Cyperaceae rhizome plant macrofossil remains in sediments prior to the dispersal of Cyperaceae pollen.

It is notable that Juncaginaceae is absent from the pollen record, despite *T. maritima* constituting a large proportion of the plant macrofossil assemblage. Juncaginaceae pollen, being produced by anemophilous plants, has a high transport capacity (Pires and Medeanic 2006). It is possible that underrepresentation of the taxa in the pollen record could be attributed to dispersal of the pollen away from the parent vegetation to other areas of the marsh or further afield.

Despite the under-representation of Poaceae species in the pollen record, there is a correspondence between the relative abundance of Poaceae pollen and plant macrofossil remains. Correspondence between the Poaceae pollen curve and the *S. alterniflora* plant macrofossil profile indicates that the species is particularly well-represented.

Chronozones and RSL

The saltmarsh sediments from the Big River Marsh BRM1 core provide a high resolution, well-dated record of recent vegetation, environmental and sea-level change around the site. Analysis of the upland pollen record allows landscape-scale changes to be established, including regional forest fire events and inferred phases of increased human presence in the area, which have the potential to be applied as pollen markers for dating the saltmarsh core. The wide radiocarbon age range in the upper sediments of the core reiterates the importance of applying a complementary dating proxy for reconstructing saltmarsh accumulation rates. The concurrence of radiocarbon dates from the upper core and signals of anthropogenic disturbance in the pollen record and dated documentary accounts of increased human presence in the region, indicate the relative accuracy of the two chronozones identified, though anthropogenic markers are subtle. The first chronozone is represented by a peak in *Plantago lanceolata* pollen levels around the late 1700s, alongside a small increase in *Ambrosia,* and corresponds with a period of sedentary occupation by the Mi'kmaq people of St. George's Bay, and European settlement of the area at the end of the 18th century. The second chronozone is represented by a second peak in *P. lanceolata* and a small increase in *Rumex* pollen levels following increased seasonal and permanent settlement of the Port au Port peninsula in the mid 1800s. Earlier signals of anthropogenic disturbance from the 1400s could be attributed to the presence of ancestors of the Beothuk, whose presence in the area is indicated in the local archaeological record (Simpson 1986). With further regional palynological and archaeological research there may be the potential to develop a third chronozone associated with the withdrawal of ancestral Beothuk populations in the area. There is some indication of reforestation in the early 1600s in the landscape surrounding Big River Marsh which may be a signal of a local depopulation event which is thought to have commenced in the 1400s throughout North America (Liebmann et al. 2016). Pollen records from the late Holocene in Newfoundland indicate a late increase in some arboreal pollen levels which may also be an indication of such an event (e.g. Brookes et al. 1985; Brown Macpherson 1995). Correlation of dated late Holocene pollen records in the region may generate a greater understanding of the population dynamics and land usage of the ancestral Beothuk people and allow earlier pollen chronozones to be developed.

The wetland vegetation record indicates phases of localised hydrological change in the saltmarsh and changes in RSL. Generally, the wetland pollen and plant macrofossil records indicate a transition from a high/upper marsh vegetation composition to a high/low marsh vegetation from ca. 1772. However, there are prior subtle fluctuations in RSL which are not reflected in regional coarser-scale studies (e.g. Daly et al. 2007; Kemp et al. 2018). High resolution studies of recent saltmarsh accumulation rate changes through pollen, macrofossil and Foraminifera analyses, combined with chronozone dating may further increase the understanding of the drivers of RSL in Newfoundland.

Conclusions

Saltmarsh sediments are often a successful source of well-preserved pollen and plant macrofossil remains from the late Holocene. However, there is a need for additional chronological information to increase knowledge of anthropogenic activities in the Port au Port region of Newfoundland and aid the precision of RSL inferences. The wide radiocarbon age range demonstrated in the upper sediments of the saltmarsh core analysed by Kemp et al. (2018) at Big River Marsh, reiterates the importance of applying a complementary dating proxy for reconstructing saltmarsh accumulation rates. Detailed analysis of the upland and wetland pollen, non-pollen palynomorph record (foraminiferal linings and fungal spores) and plant macrofossil remains of the sediments sampled at Big River Marsh produces a high resolution, well-dated recent relative sea-level, wetland vegetation and landscape change record of the site. Grouping the pollen record into upland and wetland assemblages allows local events related to hydrological change to be separated from landscape-scale changes. The upland pollen record is dominated by *Picea* and *Betula* tree pollen and corresponds well with regional pollen records from the same period. *Picea* is thought to be well-represented in the assemblage whilst *Abies*, which is a dominant species in region, and *Pinus* are deemed as under-represented. *Betula* is thought to be over-represented in the pollen record compared to regional records of species abundance. Two potential chronozones have been identified in the upland assemblage, the first represented by a peak in *Plantago lanceolata* pollen levels around the late 1700s, alongside a small increase in *Ambrosia.* The changes potentially correspond with a period of sedentary occupation by the Mi'kmaq people of St. George's Bay, and European settlement of the area at the end of the 18th century. The second chronozone is represented by a second peak in *P. lanceolata* and a small increase in *Rumex* pollen levels following increased seasonal and permanent settlement of the Port au Port peninsula in the mid 1800s. However, historic pollen markers are not as well developed at Big River Marsh compared to other records in the North Atlantic region (e.g. Fuller et al. 1998; Paquette and Gajewski 2013) and should be treated with caution. Similarly, there are no notable peaks in micro-charcoal fragments which can be reliably distinguished from natural forest-fire events.

The wetland pollen record shows an apparent under-representation of Poaceae pollen, whilst Cyperaceae and *Potamogeton* pollen are often abundant throughout the assemblage. The wetland pollen and plant macrofossil record indicate changes in local sea-level, generally showing accelerated rise from ca. AD 1700. The representation of Cyperaceae macrofossil remains in the wetland pollen profile is complex, showing a vertical off-set thought to be related to rhizome encroachment from the marsh fringe during periods of marine regression. Correspondence between the Poaceae pollen curve and the *S. alterniflora* plant macrofossil profile indicates that the species is particularly well-represented in the plant macrofossil record. Comparison of the plant macrofossil and wetland pollen profiles highlights the need for further analysis of the zonation, pollen dispersal and macrofossil representation of Cyperaceae species in saltmarshes. Future studies using plant macrofossils should distinguish between the bulbs, rhizomes, roots and stems of Cyperaceae to increase the information obtained.

Acknowledgements We thank the Department of Earth Sciences, Vrije University Amsterdam for assistance with the preparation of pollen samples. KS, HR and AW acknowledge the inspirational leadership provided by co-author Orson van de Plassche, a meticulous and energetic field scientist and leading sea-level researcher who passed away in 2009.

Author contributions KS, HR and OvdP designed the study; KS and AW undertook the pollen and plant macrofossil analyses and HR assisted with data plotting. OvdP secured funding, provided logistical support and access to laboratory facilities at the Vrije University for sample processing. The write up and figures were completed by KS, HR and SD.

Funding The Foraminifera-derived sea-level research associated with this study (published by Kemp et al. 2018) was supported by a grant from the Netherlands to OvdP and is gratefully acknowledged.

Declarations

Conflict of interest All authors declare that they have no conflict of interest.

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